Supporting Information for "Neutral Plane Control by Using Polymer/Graphene Flake Composites for Flexible Displays"

Byungil Hwang^{a, b+}, Seoyoen Lim^{a+}, Minkyu Park^a and Seung Min Han^{a*}

^aGraduate School of Energy Environment Water and Sustainability, Korea Advanced Institute of

Science & Technology, Daejeon, Republic of Korea, 305-701

^bBASF Electronic Materials R&D Center Asia, Suwon, 16419, Republic of Korea

*Corresponding author e-mail: <u>smhan01@kaist.ac.kr</u>

+These authors contributed equally to this work

Supporting Information 01.



Figure S1. (a) Images of PMMA solution, and (b) of PMMA solution with 1.0wt% of graphene flakes.

Supporting Information 02.



Figure S2. Optical microscope images of PMMA with various contents of graphene flakes: (a) PMMA without graphene, (b) 0.2 wt%, (c) 0.4 wt%, (d) 0.6 wt%, (e) 0.8 wt%, and (f) 1.0 wt%. Average grain sizes of each sample were measured as \approx 1.1 µm, \approx 1.4 µm, \approx 1.8 µm, \approx 2.4 µm, and \approx 2.9 µm for the PMMA with different graphene contents of 0.2, 0.4, 0.6, 0.8 and 1.0 wt%, respectively.

Supporting Information 03.



Figure S3. Nanoindentation results of PMMA with different types of graphene: graphene flake, RGO, and GO. (a) The extracted modulus and (b) hardness values at 500 nm as a function of graphene content in PMMA. The commercially available GO solution (Graphene Supermarket) was used to make the GO/PMMA composite. The RGO solution was synthesized by reducing the GO using hydrazine. The detailed synthesis method of RGO can be found in ref [S1].

[S1] B. Hwang, M. Park, T. Kim and S. M. Han, RSC Advances, 2016, 6, 67389-67395.

Supporting Information 04.



Figure S4. XPS spectrum obtained from (a) pristine graphene flakes, (b) RGO sheets, and (c) GO sheets. The oxygen contents of graphene flake, RGO, and GO were \sim 7.0 %, \sim 16.4%, and \sim 32.1%, respectively. The small fraction of oxygen is known to be detected in the XPS analysis of pristine graphene flakes due to the small contamination by water, CO₂, or oxygen.[S2]

[S2] M. Yi, Z. Shen, X. Zhang and S. Ma, J. Phys. D: Appl. Phys. 2013, 46, 025301.

Supporting Information 05.



Figure S5. Illustrations of neutral plane shift when the top encapsulting polymer layer is replaced with the PMMA/graphene composite of higher modulus. The graphene holds the polymer chain, which results in the increase in modulus of the polymer/graphene composite. The enhanced modulus then shifts the neutral plane toward the OLED layers that in turn reduces the bending strain imposed on the OLED layers for enhanced reliability.

Supporting Information 06.



Figure S6. Illustration of the structure of conventional OLED device and table indicating the elastic modulus and thickness of each layer used for the calculation of neutral plane position.

Supporting Information 07.



Figure S7. Schemetics of oxygen or water molecule transition through (a) PMMA or (b) PMMA with graphene flakes.

Supporting Information 08.



Figure S8. Image of transparent PMMA/graphene composites with 1.0 wt% on PC substrate.